Proceedings of the 23rd Annual British Columbia Mine Reclamation Symposium in Kamloops, BC, 1999.
The Technical and Research Committee on Reclamation

A NEW APPROACH TO TAILINGS MANAGEMENT: THE GRANULAR COVER SYSTEM

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ABSTRACT

The challenge of effectively isolating sulphide bearing waste rock and tailings requires that oxidation of sulphides be prevented and/or the escape of interstitial salt solutions from the tailings mass be prevented. The establishment of a water cover over top of tailings has been demonstrated to effectively reduce the oxidation of sulphides and thereby minimize acid generation and metal leaching.

A new approach to the control of sulphide tailings oxidation is being developed by Falconbridge Limited and Lakefield Research Limited. The technique under development involves the establishment of a composite cover of inorganic minerals, of appropriate layer thickness, hydraulic properties and composition over the deposit in such a way that both evaporation and surface run-off are greatly reduced and/or eliminated. The granular cover system is suitable to tailings deposits that have a gentle slope and do not contain large hydraulic discontinuities. The system is also best suited to geographical site locations where precipitation is not a limiting factor.

This paper describes the development of the granular cover system from bench scale testwork through to pilot field scale evaluation and summarizes the results from three consecutive years of field monitoring.

INTRODUCTION

Tailings cover evaluation tests conducted between 1995 and 1996 indicated that evaporation played a significant role in the migration of salts from tailings cover systems. The flushing of these salts has been demonstrated to result in significant surface water impacts and treatment requirements.

Initial testing indicated that the addition of a specifically designed Granular Cover System can physically alter the water balance characteristics of a tailings impoundment system and thereby reduce sulphide oxidation in sulphide bearing tailing deposits that are:

- gradually inclined,
- void of severe hydraulic discontinuities, such as those imposed by retaining dam structures,
- comprised of uniformly deposited tailings of low hydraulic permeability, and
- located in areas of significant rainfall.

Laboratory testing has shown that the Granular Cover System substantially reduces the evaporative loss of water from a tailings surface and increases the surface capture of influent precipitation. This causes a distinct change in the water balance of the impoundment. The resultant increased infiltration and decreased exfiltration causes a rise in the groundwater table, which can effectively saturate the underlying sulphide bearing materials.

The saturation of the tailings inhibits the ingress of atmospheric oxygen, even during extended periods of drought, resulting in the following improvements:

- inhibition of sulphide oxidation,
- inhibition of the escape of solutions to the surrounding environment,
- avoidance of surface erosion by reducing the velocity and channeling of surface water run-off,
- prevention of mass migration caused by freeze-thaw effects through the provision of thermal insulation (which reduces the depth of frost penetration) and a solar barrier (which slows the rate of thawing in the spring),
- prevention of dust migration through the protection of the fine tailing surface from wind erosion,
- inhibition of ferric salt leaching by providing a barrier to the capillary migration of ferrous salt solutions into the surface oxidizing layer and to the surface of the tailings deposit,
- seepage suppression by eliminating the pumping action through the tailings mass generated by crack formation and the periodic filling of these cracks with water, and
- avoidance of dam failure through the provision of an effective cover system for impoundments that require only a nominal peripheral berm.

The granular cover system relies on a design whereby each subsequent layer differs from the previous with respect to its ability to permit flow, resist erosion, reduce evaporative losses and retain water. At least one layer within the two to three layer system must provide a capillary break to the upward flow of water within the system to effectively minimize evaporative losses. An understanding of the physical characteristics of each cover layer material is, therefore, essential to the cover design. The Granular Cover System is currently under patent application by Falconbridge Limited.

TESTING PROGRAM

A variety of bench-scale tests were conducted at Lakefield Research as part of the development of the cover system. Tests included: grain size distribution testing, hydraulic conductivity (K) testing, Soil Water Characteristic Curve testing, U.S. EPA 1312 Synthetic Precipitation Leachate tests, erosion testing, and evaporation testing. Computer modeling was also completed to assess the erosional capabilities of selected cover materials based on the existing field test site watershed and the volume of precipitation that would be intercepted by the Granular Cover System. A large scale field test is currently on-going.

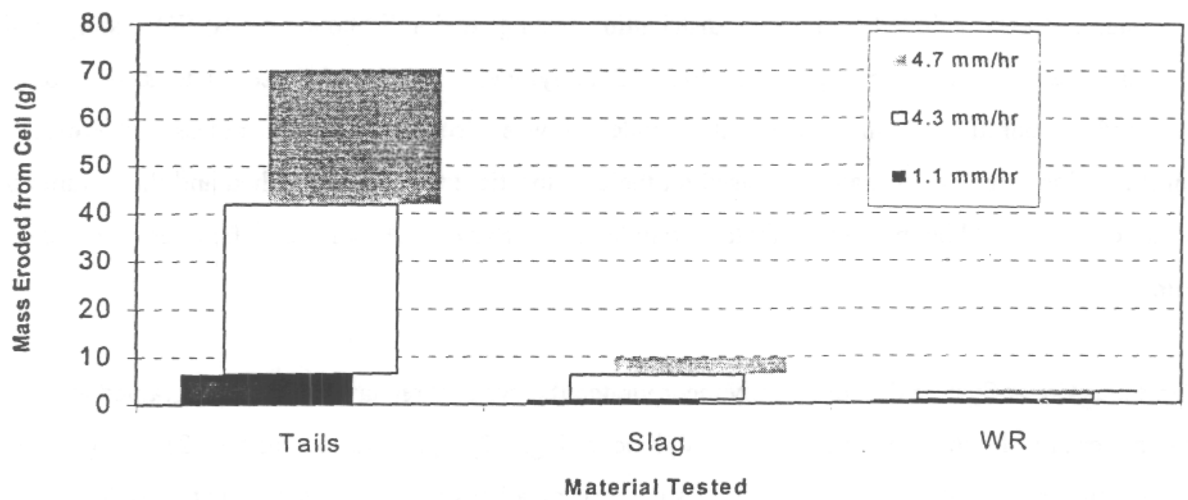
The Granular Cover System design initially incorporated the use of three layers: 1) a fine grained alkaline tailings material to lie directly on top of the sulphide tailings, 2) a granulated slag and 3) an uppermost coarse alkaline rock material. To provide a summary of all testing conducted to date would require several technical papers, therefore, only the erosion and evaporation laboratory testing programs are described below. The results of the field scale test are also discussed.

Erosion Testing

The erosion test program was designed to determine the erosion potential of coarse rock, granulated slag and alkaline (gold) tailings, from mining operations located near Timmins and Sudbury, Ontario. Testing was conducted on a fully saturated granular material to determine the flow velocity that would cause mass erosion of the materials. This information was used to determine precipitation rates that would cause surface erosion of the materials and to compare this data to naturally occurring rainfall rates for Northern Ontario to determine the stability of the materials in this setting.

The alkaline (gold) tailings (80% minus 200 Tyler mesh) did not permit a measurable flow rate through their mass during the test period. The materials' low hydraulic conductivity resulted in the erosion of the tailings even at relatively low rainfall intensities. At an equivalent rainfall rate of 1.1 mm/hour applied over a 2-minute period 36 g/m^2 of tailings were eroded from the tailings surface. Flows quickly penetrated through the tailings and resulted in large scale erosion as piping. 50-year and 100-year storm events resulted in more significant losses of 196 g/m^2 and 158 g/m^2 of tailings area. For a tailings area of 50 hectares this would equate to 98 tonnes of tailings eroded during a 50-year event. These results showed that the tailings would not serve as a reliable primary cover layer and eroded easily under an equivalent rainfall precipitation rate of 1.1 mm/hr.

Figure 1: Mass Erosion Comparisons of Each Material for Effective Rainfall Rates



The granulated slag (75% minus 20 mesh) tested had a relatively high hydraulic conductivity that permitted the capture and transfer of influent precipitation. The slag proved to be a physically stable material with only very fine particulate matter being entrained in runoff waters at lower rainfall rates. Under the 50-year storm event rainfall rate of 4.3 mm/hr, erosion of approximately 30 g/m^2 was observed. A similar degree of erosion occurred at the 100-year event rate of 4.7mm/hr with 20 g/m^2 being eroded.

The results obtained from the coarse rock (80% minus 3 cm) material showed a high hydraulic conductivity calculated to be approximately 14cm/s. The coarse rock was intended to act as the top cover layer, which would be directly exposed to the atmosphere. The 100-year Timmins storm event resulted in minimal erosion from the rock mass, with 4.2 g/m^2 being removed. No evidence of mass erosion was observed, erosion consisted of fine particulates within the runoff water. The coarse rock would act as a durable top cover layer, and protect the underlying cover system layers, however, the entrained fines may cause concern in discharging waters. Classification and washing of the coarse material should be considered in cover design where elevated suspended solids contents in surface water systems may result.

Evaporation Testing

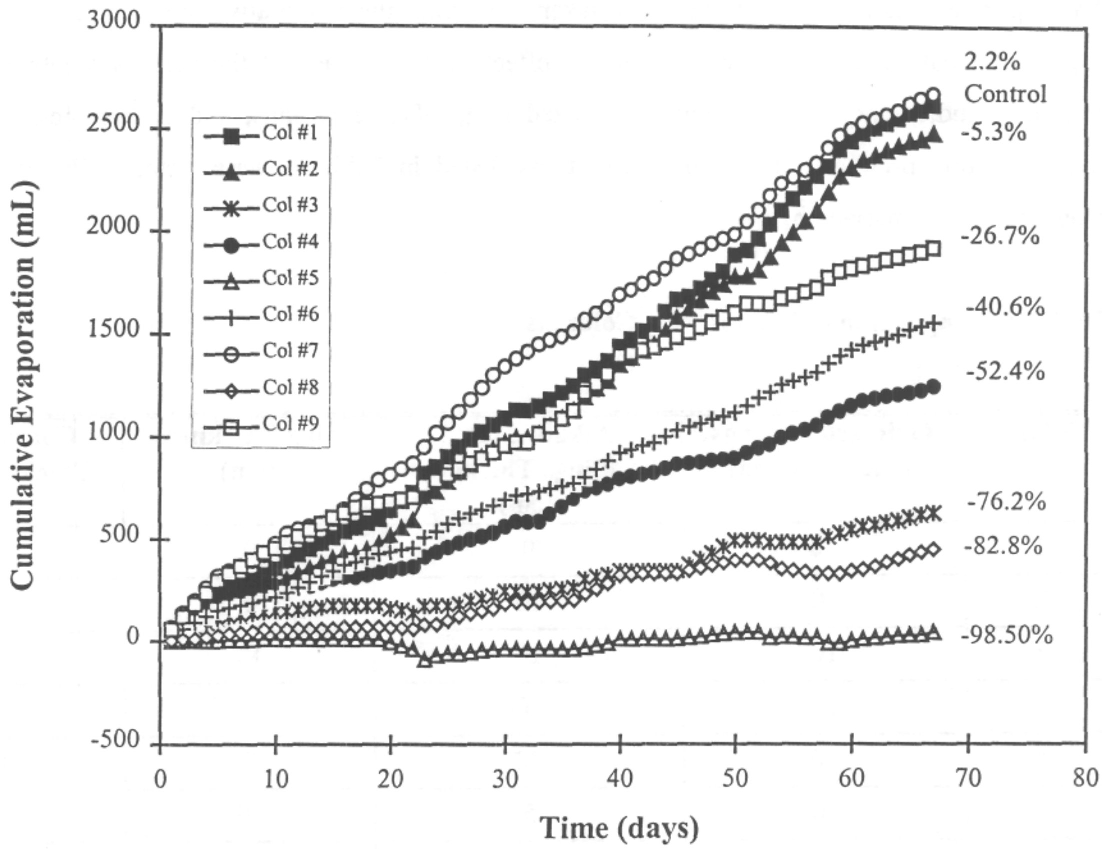
An evaporation testing program was undertaken to monitor the evaporative losses from various granular cover combinations and then to evaluate the effectiveness of each of the various combinations. The materials studied included the same granulated slag, alkaline tailings, and coarse rock tested in the erosion testing program. Nine cover variations, listed in Table 1, were tested. The results of this program are summarized below.

Table 1: Composition of Evaporation Columns

Column	Oxidized Tailings Thickness (cm)	Alkaline Gold Tailings Thickness (cm)	Slag Thickness (cm)	Coarse Rock Thickness (cm)
1	10	0	0	0
2	10	10	0	0
3	10	10	10	0
4	10	10	5	0
5	10	20	0	0
6	10	5	10	0
7	10	0	10	0
8	10	10	10	10
9	10	10	0	10

Figure 2 shows the evaporative trends for each of the columns tested. The graph shows four groupings of columns. The columns with highest amount of water loss were 1, 2, 7, and 9. The high evaporative losses from these columns showed that either the minor thickness of the covers or the presence of only one type of cover was ineffective at reducing the amount of evaporation from the underlying tailings. Column 9, which had 10 cm of alkaline tailings covered by 10 cm of coarse rock, may have allowed for the advection of air through the large pore spaces provided by the very coarse rock material used (minus 3 cm), thereby resulting in the high evaporative losses noted.

Figure 2: Cumulative Evaporation Losses from Various Cover Sequences



The next grouping of columns included 4 and 6, which both had a 15 cm cover composed of alkaline (gold) tailings and slag. Column 4 had 5 cm of alkaline tailings overlain by 10 cm of slag, and column 6 had 10 cm of alkaline tailings overlain by 5 cm of slag. While column 4 was slightly more effective at evaporation reduction, the results show that both these combinations of alkaline (gold) tailings and slag were approximately equally effective at reducing evaporation.

The covers with the next lowest evaporation rates included columns 3 and 8. Column 3 had 10 cm of alkaline (gold) tailings overlain by 10 cm of slag. Column 8 had 10 cm of alkaline (gold) tailings, 10 cm of slag, and 10 cm of coarse rock. Since the total evaporative losses from both columns were almost identical, the coarse rock material provided no significant benefit in evaporation reduction. The ineffectiveness of the rock cover was also exhibited by the similarities in evaporative losses observed in column 9 which had 10 cm of coarse rock over 10 cm of alkaline tailings, and column 2 which had a cover consisting only of the alkaline (gold) tailings.

The column with lowest recorded water loss was column 5 which had 10 cm of alkaline (gold) tailings covered by 20 cm of slag. In column 7, where only 10 cm of slag overlay the alkaline (gold) tailings, salt crystals developed at the surface indicating that the upwards migration of salt laden tailings water was able to reach the surface. The surface of column 5 did not experience any wetting throughout the duration of the test. This indicates that, while a capillary break may not exist between the tailings and slag, the low air entry value of the slag effectively limits the upwards movement of waters when the slag is placed in sufficiently thick layers.

Sensitivity Analyses

Sensitivity analyses, completed by varying the individual cover layer thickness confirmed the ineffectiveness of the waste rock material and the importance of the slag layer thickness to the cover system design. Additional refinements of the slag - alkaline tailings cover layer showed a 94% reduction in evaporation.

The results of the bench testwork showed that a two layer granular system appeared to work best at minimizing evaporative losses and providing erosion control. This system consisted of a material intermediate in grain size and hydraulic conductivity between the coarser cap and finer underlying tailings (a third layer of fine grained low sulphur tailings or alkaline material may also be used as a basal layer overlying sulphide rich tailings). The difference in grain size between the granular cover layers and their thicknesses are important in maintaining the capillary break required to reduce evaporative losses and to minimize the potential for interfacial erosion. Placement of a very coarse layer directly on top of tailings would permit high velocities of flow over the tailings with resultant erosion. Too fine grained a layer would permit the upwards migration of capillary water.

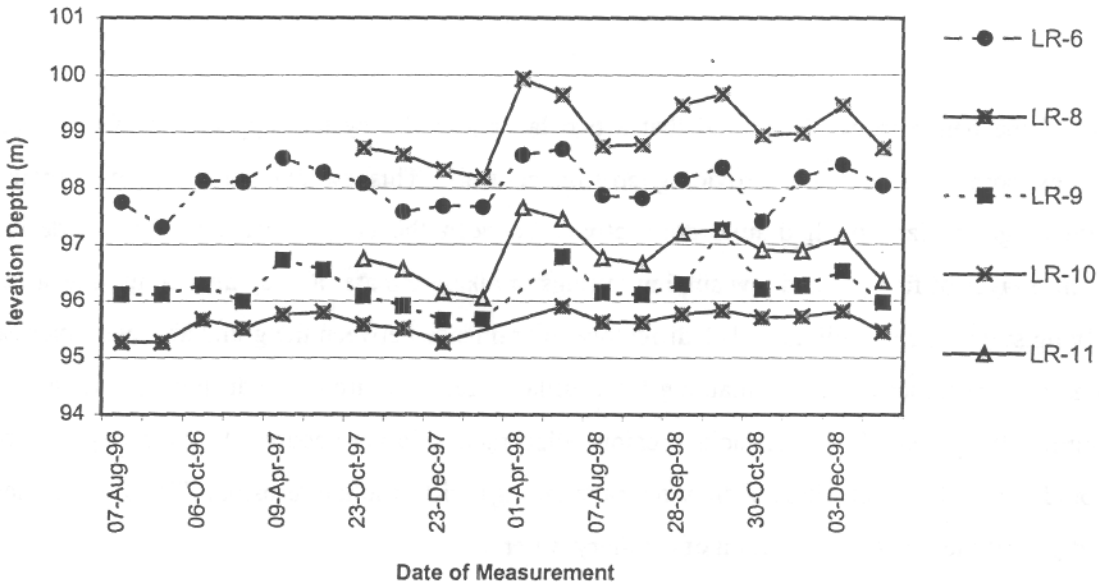
FIELD PILOT PROJECT

A small 1 hectare tailings area with no known hydraulic discontinuities was undergoing closure planning and remediation action in early 1995. Because of the site's suitability to the application of the Granular Cover System, the tailings were recontoured to establish a gently sloped deposit (3 to 4%) suitable for use as a pilot scale demonstration project. Nine monitoring wells were strategically installed around the site between July and September 1996 for the purpose of monitoring groundwater quality and groundwater elevations. Additional wells were installed in subsequent years. The discussion here is limited to the results of the water table monitoring program.

The elevation of the groundwater or water table was obtained during each sampling event prior to groundwater in the well being disturbed. Water levels were obtained using an electronic water level meter from the measuring point of each well. Monitoring of the water levels permitted determination of the effects of the granular cover placement on the groundwater table elevation within the tailings.

A hydrograph has been plotted as Figure 3. This illustrates the fluctuation and trends in water level elevations that have occurred in the monitoring wells located within the covered southern tailings basin since monitoring began in August, 1996 (LR6, LR8, LR9, LR10, and LRl 1).

Figure 3: Hydrograph of Tailings Monitoring Wells



Water level elevations for the monitor wells show:

- An average water table elevation increase of approximately 0.3 metres in monitoring wells out side of the southern tailings impoundment (non-tailings wells) from December 23, 1997 to December 3, 1998.
- An average water table elevation increase of approximately 0.85 metres in monitoring wells within the tailings granular cover (tailings wells) from December 23, 1997 to December 3, 1998.

The distance from the water table to the top of the tailings deposit at four separate times over the monitoring period, has been summarized in Table No. 3. The recorded increase in the water elevations between monitoring events April 1997 to April 1998 and December 1997 and December 1998 have also been recorded. Due to spring melt and heavy rainfall conditions, water levels in April 1997 and 1998 were near the top or above the tailings and the differences in elevations noted between the two years was minor. The levels recorded for lower flow winter periods, however, show a large difference or increase in water level between December 1997 and December 1998. These changes suggest that more water is progressively being retained beneath the granular cover as time passes. Continued monitoring would be required to confirm this observation.

Table No. 3: Top of Tailings and Water Elevation Difference at the Errington Site

Test Well ID	Thickness of Tailings	Top of Tails and Water Elevation Difference				Water Elevation Increase	
		9-Apr-97	9-Apr-97	23-Dec-97	8-Apr-98	Apr/97-Apr/98	Dec/97-Dec/98
LR-6	1.75	0.15	0.15	1.00	-0.01	0.16	0.72
LR-8	1.10	-0.03	-0.03	0.45	-0.17	0.14	0.55
LR-9	0.70	-0.17	-0.17	0.89	-0.23	0.06	0.86
LR-10	1.20	-	-	1.33	0	-	1.14
LR-11	0.80	-	-	1.04	-0.26	-	0.98

1. Negative differences imply the water table is above the top of the tailings.
2. Measurements in metres.

SUMMARY

Application of the Granular Cover System at the Errington property (Sudbury Ontario) was completed for two purposes: 1) to assist in the close-out and reclamation of the property, and 2) to provide a field pilot scale demonstration project for testing of the granular cover system.

A comparison of the water level elevations found in the tailings wells within the granular cover system from December 23, 1997 to December 3, 1998 reveal an average water table elevation increase of approximately 0.85 metres. An average increase of approximately 0.3 metres was documented for the non-tailings wells over the same period. These results would indicate that the granular cover is causing a proportionally higher increase in the elevation of the water table within the tailings impoundment. Monthly variations in the water level elevations, however, minimize and obscure the above noted rise in the water table and need to be characterized along with their relationship to climatic events to better understand the true effect that the granular cover is having on the tailings.

REFERENCES

Selley, R.C. 1982. An Introduction to Sedimentology, second edition. Academic Press Inc., New York. 417 p.